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A Life Cycle Cost Comparison of Flexible Versus Rigidpavements in Nigeria: Case Study of Papalanto - Sagamu Road

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--***ABSTRACT***--

The condition of roads in Nigeria, most of which are made from asphalt, is generally considered unsatisfactory. This has led to calls for a blanket switch from asphalt pavements to concrete pavements for new road construction. This study examines the characteristics and relative advantages of the two pavement types; and carried out the design and life cycle cost comparison of a case study road with heavy traffic and poor subgrade conditions. The results indicate that, the initial cost of construction is actually less for the concrete pavement by 12% when compared with the asphalt alternative, while the life cycle cost analysis further yielded an advantage of 36% for the concrete pavement. The paper therefore recommends that major roads, particularly those on the national and international transit corridor, being of heavy traffic, should be reconstructed as the need arises, as concrete pavements. The paper however further recommends that, axle load control should be enforced through the introduction of weigh bridges and that routine maintenance should mandatorily be carried out, as even the best constructed concrete pavements have failed due to lack of routine maintenance like clearing the road verges of weed and road sand and desilting of drainage structures.

***Key Words**: Asphalt pavement; Concrete Pavement; Flexible Pavement; Rigid Pavements; Economic Analysis.*

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I. Introduction

The history of road construction in Nigeria is traceable to Lord Lugard, first on a mule road from Zaria to Zungeru in 1904 and then a motorable road from Ibadan to Oyo town in 1906 (Dutum, 2022). Modern road development commenced as a deliberate effort in 1925 when the Communication Board was established to prepare plans for skeleton trunk road system between the major administrative centers of the nation (Owen, 1988). Since then, the development of the road network in Nigeria has grown to 194,000Km out of which about 37.000Km are paved (CBN, 2003).

Road pavements in Nigeria have historically been made from asphalt (also known as flexible pavements) which is a controlled mixture of penetration grade bitumen and mineral aggregates (crushed rock) of appropriately graded particle sizes. Until recent times, concrete paved roads, also known as rigid pavements were limited to short stretches or estate road networks of about 5km or less. Notable in the Southwest region was the short stretch of about 1km at the approach to the Ewekoro Plant of the West African Portland Cement Company (now Lafarge Africa) along the Ota – Abeokuta Road. In recent times however, notable additions to concrete pavements include the Itori – Ibese Road, and the Kaba-Obajana Road, both leading to the respective Dangote Cement Factories at those locations; as well as the Apapa Oshodi Expressway, leading to the Apapa Ports in Lagos Nigeria.

The widely heldview that concrete pavements, have a high initial cost, low maintenance cost and longer life span, when compared with asphalt pavements, all things being equal. However, given the economic reality in Nigeria today, where the country depends on 100% importation for its bitumen needs, but is self-sufficient in cement, the distortion in the foreign exchange market and the perceived monopoly of the cement market by a few players, all things may not be equal after all.

Furthermore, in recent times the Nigerian Minister for Works – a civil engineer, has faced significant push-back in his campaign for all new roads in Nigeria to be of concrete pavement construction (Punch, 2023). This he believed could be the panacea for the frequent failures a number of new roads, sometimes within few years of construction.

The aim of this paper therefore, is to re-examine the facts of the matter using a case study design, based on traffic data from the Papalanto Sagamu Road, Ogun State Nigeria;prevailing materials prices;functional classification of roads; the standard practice in the construction ecosystem and the emerging reality of economic and industrial development of the country. It is hoped that some salient points that may not have been taken into consideration would be highlighted and appropriate recommendations made for the attention of relevant stakeholders

The objective is to do a model design for the two pavement types and work out theof initial cost and life cycle cost respectively based on the Net Present Value (NPV) approach, and to juxtapose that with global benchmarks and best practices.

II. Literature Review

2.1 Performance Characteristics of Asphalt and Concrete Pavements Respectively

The performance characteristics of road pavements is scientifically rooted in the AASHTO Road Test conducted in Ottawa Illinois in the 1950s and the several revisions and updates that have followed it. The widely accepted procedure as well as prediction models for the performance of both flexible and rigid pavements, was developed from this study. In particular, basic equation for flexible pavement was developed thus:

$$\log W_{t18} = 9.36 \log (SN + 1) - 0.2 + \frac{\log[\frac{4.2-p_t}{(4.2-1.5)}]}{0.4+[1094/(SN+1)^{5.19}]} + \log\frac{1}{R} + 0.372(s_i - 3.0) \qquad (1)$$

(Yoder and Witczak 1975)

Where,

W_{t18} is the number of 18-kip (80KN) single-axle load applications at the end of time t;

SN is the structural number which is a measure of the structural strength of the pavement;

R is the climatic or regional factor;

S is the function of the subgrade; and

P_t is the terminal Pavement Serviceability Index (PSI) which is the lowest serviceability that can be tolerated on the road, usually taken as 2.0 – 2.5

For rigid pavements we have:

$$\log_{10}(W_{18}) = Z_R \times S_o + 7.35 \times \log_{10}(D+1) - 0.06 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.5-1.5}\right)}{1+\frac{1.624\times 10^7}{(D+1)^{8.46}}} + (4.22 - 0.32p_t)\times \log_{10}\left[\frac{(S'_c)(C_d)(D^{0.75}-1.132)}{215.63(J)\left(D^{0.75}-\frac{18.42}{\left(E_c/k\right)^{0.25}}\right)}\right]$$

(2)

(Yoder and Witczak, 1975)

where: W_{18} equals predicted number of 80 kN (18,000 lb.) ESALs

Z_R equals standard normal deviation

S_o equals combined standard error of the traffic prediction and performance prediction

D equals slab depth (inches)

p_t equals terminal serviceability index

ΔPSI equals difference between the initial design serviceability index, po, and the design terminal serviceability index, p_t

equals modulus of rupture of PCC (flexural strength)

Cd equals drainage coefficient

J equals load transfer coefficient (value depends upon the load transfer efficiency)

Ec equals Elastic modulus of PCC

k equals modulus of subgrade reaction

2.2 Factors affecting the performance of pavements in service

Equations 1 and 2 comprehensively capture the variables that govern the performance of pavements in service. These variables are further discussed below:

Traffic Factors: This refers to the volume of traffic and its classification, axle loads imposed on the road by heavy duty vehicles and the frequency of repetition of these axle loads. Indeed, this is probably the most critical factor affecting the service life of a road pavement.

Drainage Factors: this refers to the availability, effectiveness and efficiency of the drainage system of the road. The absence of an affective drainage system leads to stormwater ponding in valley sections of the road profile which exposes the subgrade to prolonged wetting and its subsequent weakening.

Subsoil Condition: The subsoil is the ultimate recipient of all traffic loads; hence its stability is very critical to the stability of the pavement. At the design stage the strength of the subgrade is reported in terms of the

California Bearing Ratio (CBR) or in terms of its modulus of elasticity. Whichever way, it is important that the strength of the subgrade has been properly determined at design and that thisstrength is not compromised during the service life of road.

Environmental Factors: this includes frost conditions, as well as excessive heat leading to high temperatures that can cause the softening and subsequent loss of stability of asphalt wearing courses. Rigid pavements too can suffer from the effect of temperature gradient between the surface and the bottom of the concrete.

2.3Advantages and DisadvantagesAsphalt and Concrete Pavements Respectively

The advantages and disadvantages of flexible and rigid pavements are highlighted in Table 1, from which it can be seen that none of the pavement types is without its pros and cons. However, the points that stand out as the focus of this study are initial cost, maintenance cost and consequently the life -cycle as well as local availability.

Table 1: Advantages of Flexible Versus Rigid Pavements

	Flexible Pavement	Rigid Pavement
1	Relatively low design life, 10 – 20 years	Design life of 30 years if well-constructed
2	Low tolerance for pockets of weakness in subgrade	Can be built on relatively subgrade of subgrade of relatively low strength.
3	Established installation procedure due to long history of use	Construction to standard restricted to few companies
4	Good riding quality	Poor riding quality due to presence of joints
5	Susceptible to damage from petrol and similar mineral oils, therefore unsuitable for fuel stations and similar places	Resistant to damage from mineral oil and similar chemicals.
6	High maintenance cost but easier to repair	Low maintenance requirement but difficult and expensive to repair when that becomes necessary
7	Adequate number of experienced workmen for production and placement	Dearth of trained technical manpower that can deliver the expected outcome.
8	Perceived low installation cost	Perceived high installation cost.
9	The key component – bitumen is an imported item and cost is highly susceptible to variations in exchange rate and the international oil market	The key component – Portland cement is locally produced.

2.4 Present condition of selected concrete and asphalt pavements in Nigeria.

An overwhelming majority of pavements in Nigeria are of asphalt, however there is an increasing push for more pavements to be made from concrete, particularly since the country is now self sufficient in cement production and riding on the received wisdom that concrete pavements have a longer life than asphalt pavements.

However, the present unsatisfactory condition of roads in Nigeria may not be due to the type of pavements, given that even the relatively new concrete pavements in Nigeria have also failed in several sections. Typical example is shown in Plate 1 – the Itori – Ibese road leading to Dangote Cement Factory, Ibese, made from concrete pavement and opened to traffic in 2016 (NAN, 2016).

Plate 1: Failed portion of Itori – Ibese Concrete Pavement, commissioned in 2016 (6.936387,3.222095)

Plate 2 shows a failed section of the Ota - Abeokuta Road, by Wasinmi (6.976380, 3.221807)

It is instructive to note that the Ibese – Itori – Ota axis is the major route for cement trucks from Lafarge Africa and Dangote cement plants respectively. These two companies have a combined production capacity of 9M metric tons per annum from three plants located on the axis (Apampa, 2016).Most of these are evacuated by road using the type of trucks shown in Plate 2.

Plate 2: Failed Portion of Ota Abeokuta Asphalt pavement (GPS coordinates: 6.976380, 3.221807)

III. Methodology

The methodology adopted for this work is to carry out a basic engineering pavement design of the Papalanto – Sagamu road using traffic data obtained from a 2020 volume survey of the road (Daodu, 2020)

The design standard adopted is the Nigerian Federal Ministry of Works,"Highway Pavements Materials Design Manual" (FMW, 2013), which adopts the design charts of the UK Transport and Road Research Laboratory.

The evaluation of material quantities is according to the procedures of the Civil Engineering Standard Methods of Measurements (CESMM 4) of the Institution of Civil Engineers.

The approach is a basic comparison of the cost per km of road derived from the design outputs of the two pavement types, given the same design inputs.

Cost elements are based on standard rates prevailing in Nigeria as of December 2023.

A standard maintenance program was assumed for each of the two pavement types.

Life Cycle Cost analysis was based on the Net Present Value approach, using the Monetary Policy Rate (MPR)of 18.75% announced by the Central Bank of Nigeria (CBN) in December 2023 (CBN, 2024). Future cost of maintenancewere factored for inflation using a 40-year historical average (1996 – 2024) of 13.44% as obtained from the National Bureau of Statistics (Trading Economics, 2024)

IV. Results and Discussion

4.1 Traffic Analysis and Pavement Design Input Data

Data froma volume survey of the case study road (Papalanto to Sagamu) carried out in February 2020 was processed to obtain the design input data presented in Table 2.

Table 2: Design Input Data

S/N	Design Parameter	Value	Remark
1	**Traffic Characteristics**		
	ADE	2160	From Volume Count
	Growth rate i	4%	Assumed
	Growth factor	11.304	FMW, 2013

	$f_y = 365(1+0.01i)*[(1+0.01i)^y -1]/(0.01i)$		
	Design Life	20 years	
	ESA	488120	
	Design Traffic Class	T2	0.3<T<0.7 (FMW,2013)
2	**Subgrade Engineering Properties**		
	Subgrade CBR	4%	From laboratory test results
	Resilient Modulus Mr (1500*CBR)	6000	FMW, 2013
	Subgrade Strength Class	3 - 4	

4.2 Design Output

Flexible Pavement Design Output

There are two flexible pavement design methods recommended by the Federal Ministry of Works, the Asphalt Institute Method and the Mechanistic design procedure. The former has been adopted in this work. The design input data of Table 2 was processed to obtain the design output presented in Table 3 and further graphically represented by the typical section of Figure 1.

Table 3: Flexible Pavement Design Output

Pavement Material	**Thickness**
Asphaltic Concrete Wearing Course	50mm
Asphaltic Concrete Binder Course	80mm
Crushed Stone Base Course,	300mm
Lateritic Subbase, CBR 30%	200mm
Subgrade, CBR 4%	

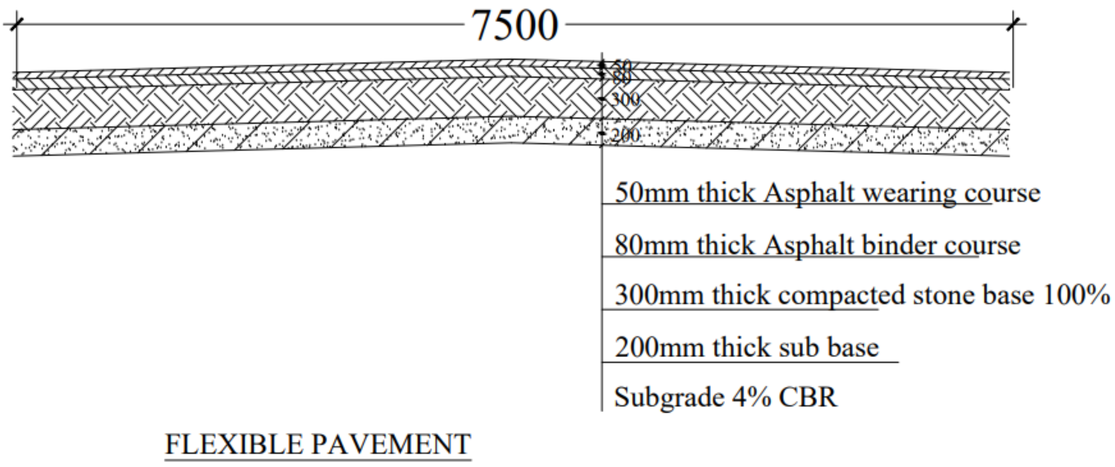

Figure 1: Design output for flexible pavement

Rigid Pavement Design output

The design procedure adopted is the Portland Cement Association method as recommended in the Nigerian Federal Ministry of Works Pavement Design Manual. As done for flexible pavement design, the design input data of Table 2 was processed resulting in the design output graphically depicted in Figure 2 below:

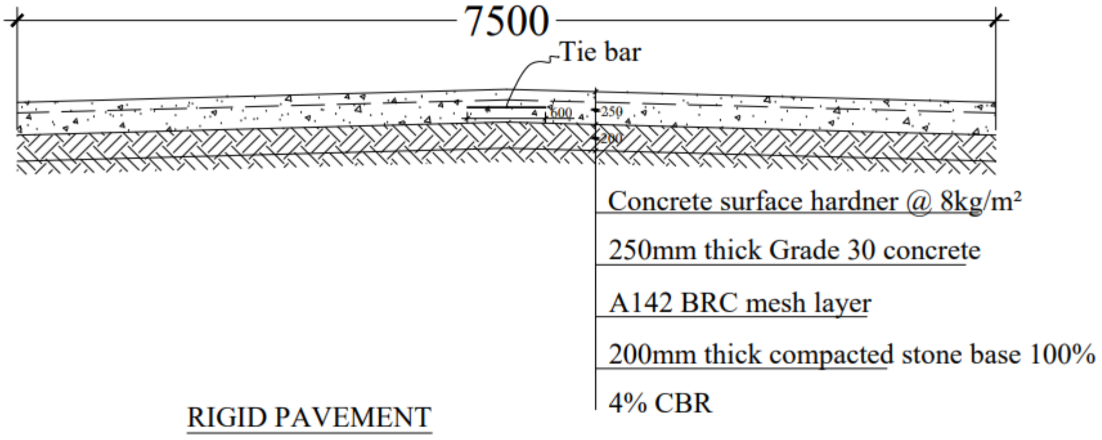

Figure 2: Design output for rigid pavement

4.3 Life Cycle Cost Analysis

New Construction

Using the design output of Figures 1 and 2, the Bill of Engineering Measurement and Evaluation (BEME) was developed for the two pavement types. The rates adopted for this comparison are the prevailing industry rates obtained from a number of ongoing projects in the South west of Nigeria for the year 2023, to which the author is privy. Furthermore, the rate for concrete Grade 30 wasbased on the current price from a major ready-mix supplier in the area (Lafarge, 2023) and marked up appropriately for site workmanship and establishment cost.

Equally worthy of note is that these cost computations are for the purpose of comparison only and do not indicate the unit cost of construction of the respective pavement types, having not taking into consideration site specific items like excavation, filling, drainage etc.

The BEME for Flexible pavements is presented as Table 1, while that for Rigid Pavements is presented as Table 2.

Table 1: Flexible Pavement BEME for Designed Road Section on Prepared Subgrade

S/N	**DESCRIPTION**	**QTY.**	**UNIT**	**RATE**	**AMOUNT (NGR)**
1	Compacted stone base 200mm thick	1600	M3	25,000	40,000,000.00
2	Shape and compact formations as specified to 100% B.S. compaction.	7,500	m^2	500	3,750,000.00
3	Provide and lay prime coat using MCO or MCI cut back bitumen at 0.9 litres per sq.m including blinding with sand or quarry fine.	7,500	m^2	500	3,750,000.00
4	Provide and spray bituminous tack coat as directed.	7,500	m^2	500	3,750,000.00
5	Provide, lay and compact asphaltic concrete binder course to a compacted thickness of 70mm as specified.	7,500	m^2	20,000	150,000,000.00
6	Provide, lay and compact asphaltic concrete wearing course to a compacted thickness of 50mm as specified.	7,500	m^2	15,000	112,500,000.00
	TOTAL, FLEXIBLE PAVEMENT PER KM				**313,750,000.00**

Table 2: Rigid Pavement BEME for Designed Road Section on Prepared Subgrade

S/N	DESCRIPTION	QTY	UNIT	RATE	AMOUNT (NGR)
1	Compacted crushed stone sub-base/ base, 100mm thick	800	m3	25000	20,000,000.00
2	Concrete Grade 30 as rigid pavement, 250mm thick, floated finish, topped with approved concrete hardener (measured separately)	1875	m3	105000	196,875,000.00
3	Concrete hardener applied to wet concrete at the rate of 10kg/m2 and finished with power float	7500	m2	2000	15,000,000.00
4	fairfaced side forms with groves at the butting side, 300mm, braced as appropriate	80	m2	6500	520,000.00
5	BRC mesh A142, single layer	7500	m2	1800	13,500,000.00
6	25mm diameter dowel bars @ 300mm centres, painted one end	35	tons	650000	22,750,000.00
7	12mm diameter tie bars @ 300 mm centres along the longitudinal joint	2	tons	650000	1,300,000.00
8	Provide joint sealant for contraction joints at 6m c/c and expansion joint at 30m c/c	1300	m	300	390,000.00
	TOTAL, RIGID PAVEMENT PER KM				**270,335,000.00**

Table 3: Assumed Maintenance Program for the Two Pavement types

S/N	Frequency	Flexible Pavement	Rigid Pavement
1	All year round, every year	Control of Vegetation and Road Sand at Verges	Control of Vegetation and Road Sand at Verges
2	5th year	30mm thin overlay	Resealing of joints
3	10th year	Asphalt overlay 50mm thick	Re-sealing of joints
4	15th year	Asphalt overlay, 30mm thick	Re-sealing of joints
5	20st year	50mm thick overlay	Repair of spalling concrete; re-sealing of joints
6	25th year	30mm overlay	re-sealing of joints

Table 4: Present Cost Elements of Maintenance Program for FlexiblePavement (per Km)

S/N	Item	Present Cost (PC)/ year ₦	Inflation factor @ 13.44% * PC*(1+r)^n	Inflation Factored Cost₦
1	Control of vegetation and road sand (All year round, every year for 25 years	6,480,000.00	See Table 6	
2	30mm thick asphalt overlay in the 5th year	71,250,000.00	(1.1344)^5 = 1.8786	133,850,025.00
3	50mm thick overlay in the 10th year	112,500,000.00	(1.1344)^10 = 3.5291	397,023,750.00
4	30mm thick overlay in the 15th year	71,250,000.00	(1.1344)^15 = 6.6297	472,366,125.00
5	50mm overlay in the 20th year	112,500,000.00	(1.1344)^20 = 12.4544	1,401,120,000.00
6	30mm overlay in the 25th year	71,250,000.00	(1.1344)^25 = 23.3937	1,666,801,125.00

Table 5: Present Cost Elements of Maintenance Program for Rigid Pavement (per Km)

Rigid Pavement				
S/N	Item	Present Cost	Inflation factor @ 13.44% *	Inflation factored Cost @ 13.44% * (₦)
1	Control of vegetation and road sand	6,480,000.00	1.0	6,480,000.00
2	Resealing of joints, 5th year	390,000.00	1.8786	732,654.00
3	Re-sealing of joints, 10th year	390,000.00	3.5291	1,376,349.00
4	Re-sealing of joints, 15th year	390,000.00	6.6297	2,585,583.00
5	Repair of spalling concrete, 20th year	107,458,000.00	12.4544	1,338,324,915.20
6	Resealing of joints in 20th year	390,000.00	12.4544	4,857,216.00
7	Resealing of joints in 25th year	390,000.00	23.3937	9,123,543.00

Table 6: Net Present Value (NPV) Comparisons

S/N	**Year**	**NPV factor [1/(1+i)^n]**	**Flexible Pavement**		**Rigid Pavement**	
			Construction and Maintenance Cost	NPV	Construction and Maintenance Cost	NPV
1	1st Year	1.0	313,750,000.00	313,750,000.00	270,335,000.00	270,335,400
2	5th Year	0.4235	133,850,025.00	56,685,485.00	732,654.00	310,278.97
3	10th Year	0.1793	397,023,750.00	71,186,358.38	1,376,349.00	246,779.38
4	15th Year	0.0759	472,366,125.00	35,852,588.89	2,585,583.00	196,245.75
5	20th Year	0.0322	1,401,120,000.00	45,116,064.89	1,343,182,131.20	43,250,464,63
6	25th Year	0.0136	1,666,801,125.00	22,668,495.30	9,123,543.00	124,080.18
7	Year 1 - 25	0.6006	162,000,000.00	97,297,200.00	162,000,000.00	97,297,200.00
8	**Total**			**642,556,192.46**		**411,760,448.91**
	$PV = PP[\frac{1-(\frac{1+g}{1+i})^n}{i-g}]$ i=18.75%; g=13.44%					

4.3 Discussion of Results

The outcome of the BEME comparison exercise for the two pavement types as shown in Tables 1 and 2 is quite instructive given the conventional wisdom that concrete paved roads have a higher initial cost construction compared with bitumen surfaced roads. While Table 1 returns a value of N270,335,000.00 per km for concrete pavements, the corresponding figure for flexible pavement as shown in Table 2 is N313,750,000.-per kmfor a 7.5m wide 2-lane road.

The percentage cost difference being in the range of 12-15% of each other, may actually be thought of, as withing the same cost bracket. This in fact is an established trend for roads designed for heavy duty traffic and poor subgrade conditions (Moyer and Lampe, 1970; Ashok and Ashwini, 2017, Akeke et al., 2018).

Despite being in the same cost bracket however, concrete pavement definitely has the advantage, given the established performance record in terms of low maintenance cost and longer life. The life cycle cost comparison of Table 6 shows this in bold relief, with NPV for flexible and rigid pavements being N642,556,192.46 and N411,760,448.91 respectively, over a 25-year period – a 36% advantage for rigid pavements. Furthermore, cement which is the distinguishing and key component of a Portland cement concrete road is locally produced, while bitumen is an imported commodity. This makes for stable pricing and the certainty of availability for planning purposes.

However, there are factors that predispose roads in Nigeria to fail much sooner than the design life. These have been mentioned earlier but are again highlighted thus:

Excessive Axle Loads: Heavy goods vehicle in Nigeria often exceed the prevailing international limits. Petrol tankers have a payload of 33000 to 45000 litres. Likewise cement trucks are increasingly of the 900-bag capacity type (as shown in Plate 1) which implies a pay load of 45 tons. These give rise to gross vehicle weights of 45 – 70 tons, often beyond the axle loads used for analysis of traffic at the design stage. There is certainly a need for weigh bridges to limit the Gross Vehicle Weights of vehicles accessing the public highways. The lack of this control speeds up the deterioration of the pavement, regardless of the pavement type.

Maintenance Practice: Absence of routine maintenance leads to the development of environmental conditions that are unfavourable to the pavement structure. Routine activities like vegetation and dust/ grit control on the road ensure proper drainage of stormwater and reduces abrasion of the surface course. The lack of these accelerates the deterioration of the pavement deterioration process, irrespective of pavement type.

V. Conclusion and Recommendation

5.1 Conclusion

The paper presented a comparison of the characteristics and relative advantages of flexible and rigid pavements respectively, and carried out the design of a model of the two pavement types using traffic data from Papalanto – Sagamu Road. It went further to work out the Bill of Engineering and Measurement and Evaluation for the two alternatives and arrived at a cost of N313,750.00 per kilometer and N270,335.00 per km for Asphalt and Concrete pavements respectively. The paper interprets this result as indicative that concrete pavements can actually have a lower initial cost than asphalt pavements, by as much as 12%, in addition to its clear advantage of some 36% in life cycle cost analysis.

The findings of this study arein line with established global trend (Moyer and Lampe, 1970; Ashok and Ashwini, 2017) for roads designed for heavy duty traffic in poor subgrade conditions, which the traffic data fit into. The traffic data having been obtained on a Federal Highway on the International Transit Corridor, the conclusion of this study could be applicable to other Federal Roads in this category such as the Lagos – Ota – Abeokuta Road and the East – West Road.

The study however, pointed out that a blanket switch flexible to rigid pavements is not a cure all for the problem of premature failure of road pavements, giving an example of a rigid pavement in the same area that has failed within five years of service. Equally important is the need for axle load control and the institution of routine maintenance procedure (clearing of road sand and vegetation at road verges, de-silting of drainage structures, timely sealing of cracks, etc.).

5.2 Recommendations

The paper makes the following recommendations:

i. Major Federal Roads, particularly those on the national and international transit corridor, being of heavy traffic, should be reconstructed as the need arises, as concrete pavements. A proper design would actually place the initial cost of the two alternatives in the same bracket, thereby giving the concrete pavement a clear edge even before a life-cycle analysis is carried out.

ii. The decision of pavement type for other roads in the light to medium traffic category should be based on a rigorous life cycle analysis and take into consideration other factors such as local availability of materials, trained technical manpower, and price distortions from foreign exchange issues prevalent in the Nigerian economic space.

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